Research on Forest Management Based on Forest Balanced Carbon Sink Model

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Abstract: With the increasing impact of climate change, forest plays an increasingly crucial part in global warming inhibition. We established a Forest Balanced Carbon Sink model to simulate the carbon exchange in order to help sequester more carbon. Moreover, we built a Balanced Decision Model, based on the Game Theory, balancing evaluations from the view of economy, biodiversity, tourism and carbon sequestration, to form a forest management plan which consists of rotation period and felling intensity. Then Our model is applied to Hongya Forestry to ascertain the best management plan. The results show that cutting period of 6.31 and cutting intensity of 0.17 is one of the best management plans.

1. Introduction

Forests convert carbon dioxide and water into biomass through photosynthesis, this fixes a large amount of carbon dioxide in the branches, roots, leaves and other parts of the plant, which transmits carbon to the soil through the roots, dead branches and leaves[1]. There is a huge amount of carbon fixed by forests through the carbon sequestration effect every year, which plays a very important role in reducing the concentration of greenhouse gases in the atmosphere and slowing down global warming[2].

Improving carbon sequestration of forests is an important issue in forest management, appropriate harvest for healthy forest growth is an important part of forest management plans. Harvesting plays an important role in the forest, as it is necessary when the growth rate is affected or slowed down by the high density of trees[3]. In this paper, we develop a carbon sequestration model to determine how much carbon dioxide a forest and its products can be expected to sequester over time. We also make a forest management plan that balances the various ways that forests are valued to inform forest managers of the best use of a forest.

2. Forest Balanced Carbon Sink Model

We develop a Forest Carbon Balance (FBCS) model to calculate the maximum carbon sequestration in forests from four aspects shown in Eq 1:

$$CS = Fr_{in} - Fr_{out} + WP_{in} - WP_{out} + Soil \tag{1}$$

Where, CSrepresents plant carbon sink of forest at time *t*. Fr_{in} represents CO_2 uptake of forest at time *t*. Fr_{out} represents CO_2 release from forest at time *t*. And the difference between Fr_{in} and Fr_{out} represents the carbon sink balance of plants. WP_{in}represents CO_2 uptake by wood products at time t. WP_{out}represents CO_2 release from wood products at time *t*. And the difference between WP_{in} and WP_{out} represents the carbon sink balance of the wood products. $Soil$ represents CO_2 uptake by soil at time *t*.

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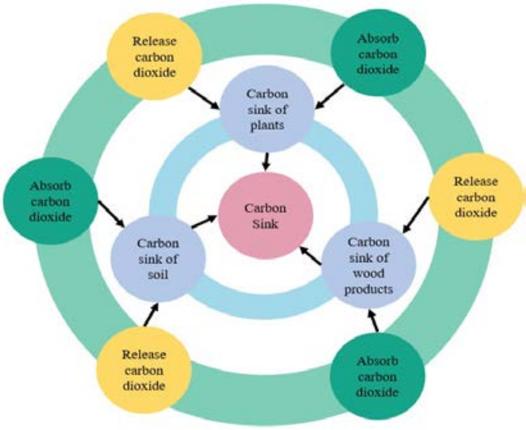


Figure 1: Specific content of Forest Balanced Carbon Sink Model schematic diagram

3. Carbon Sink Balance of Plants

The carbon sink balance of plants is represented by the difference between Fr_{in} and Fr_{out} in Eq 1, and we calculate the carbon sink balance of plants from two perspectives: the amount of carbon dioxide absorbed by plants and the amount of carbon dioxide released by plants.

3.1 Carbon Sink of Plants

3.1.1 The Amount of Carbon Dioxide Absorbed by Plants

The amount of carbon dioxide fixed by the forest at moment t (Fr_{in}) was obtained and calculated as shown in Eq2:

$$Fr_{in} = a \cdot B(t) \cdot A_g \cdot CC \tag{2}$$

Where, a represents forest area. $B(t)$represents the carbon equivalent per hectare of forest at moment t. A_g represents denotes age class coefficient. CC represents CO_2 weight per 1 T of carbon in biomass. And CO_2 contains one carbon molecule and two oxygen molecules. The atomic weight of carbon is 12 (u) and the atomic weight of oxygen is 16 (u). The weight of CO_2 in a tree is determined by the ratio of CO_2 to C. This ratio is defined as the carbon matter CO_2 factor with a value of $44 \div 12 = 3.67$.

We use Chapman Richards Model to measure the growth rate of tropical rainforest, temperate deciduous forest, and coniferous forest, and the expression of forest biomass carbon content per unit area at time t is Eq 3:

$$B(t) = b_1(1 - e^{-b_2 t})^{b_3} \tag{3}$$

Where, $b_1, b_2, b_3$are empirical parameters based on earlier studies. The corresponding b_1, b_2, b_3, for tropical rainforest, temperate deciduous forest, and coniferous forest are shown in the Table 1:

Table 1: statistics for different kinds of forest

Growth rate	Forest type	b_1	b_2	b_3	Source
Fast	Tropical rain forest	428.01	0.0253	2.64	Liu et al. 2017[4]
Moderate	Temperate deciduous forest	198.6	0.0253	2.63	Asante er al.2016[5]
Slow	Boreal forest	103.07	0.0245	2.69	Hltmark, 2015[6]

A_g was used to characterize the differences between the growth rates of trees of different ages, $A_g$was related to tree species and temperature conditions, and the equation was calculated as shown in Eq 4. Empirically we take the average of temperate trees, $\beta = 1.1$ and $\gamma = 0.3$.

$$A_g(t) = \beta e^{-\gamma t} \tag{4}$$

3.1.2 The Amount of Carbon Dioxide Released by Plants

We quantified the carbon dioxide produced by plant respiration using the respiration coefficient, and the quantified equation is shown in Eq 5:

$$Fr_{out} = a \cdot B(t) \cdot A_g(t) \cdot B_r \tag{5}$$

Where, B_r indicates the biological respiration coefficient.

3.2 Carbon Sink of Wood Products

3.2.1 The Amount of Carbon Dioxide Absorbed by Wood Products

We assume the harvesting method is clean cutting and the rotation interval(*I*) varies from 1 to 50. We simulate the felling cycle and the intensity (h_p) of felling under the rotation method. We note the sequence of harvest in the simulation as k, the felling occurs at *n*, and the biomass carbon content of the k^{th} felled timber is equal to the carbon content of all wood products in period *t* (WP_{in})

We divide the wood products into three categories according to their different usages and find the approximate range of life span for the three types of wood products. The results for the life span of wood products for l_u are shown in the following table 2:

Table 2: Life span of different wood products

Types of wood products	Building materials and furniture	Packing, books, ships, etc.	Household paper, fuel, etc.
l_u (year)	60-80	10	1

Since each type of wood product is manufactured with a certain amount of raw material loss, we define the ratio of the amount of wood actually used to the amount of trees cut down as the wood utilization rate ut_u, and to facilitate the calculation of the amount of carbon sequestered at each time we convert the amount of carbon sequestered by wood to each year of its life cycle. In summary, we calculated the annual carbon sequestration from the time of harvesting to the end-of-life of the wood products by Eq6:

$$WP_{in} = \sum_{k=1}^{K} \sum_{u=1}^{U} \sum_{n}^{N+l_u} WP_k \cdot ut_u \cdot \frac{p_u}{l_u} \tag{6}$$

$$WP_k = h_p \cdot a \cdot B_t \cdot A_g \tag{7}$$

3.2.2 The amount of carbon dioxide released by wood products

We calculate the amount of carbon released during the whole process from the beginning of decay to the end of decay by Eq8:

$$CO_2 = \sum_{t=1}^{T} \frac{Er(t) \cdot Re(t)}{(1+r)^t} \tag{8}$$

Where, *r* represents carbon discount rate. $Er(t)$ represents amount of CO_2 released per unit volume of wood products. $Re(t)$represents number of decaying wood products. *t* represents the time from the end-of-life cycle to the end of decay is considered as the beginning of decay at t =1 and the end of decay at T .

When *t* tends to infinity, it can be approximated as a discount of the carbon dioxide contained in the residue carbon biomass(*carbon*) with a discount rate of β_2 and a discount value taken as 0.8. The computational equation is shown as Eq 9:

$$CO_2 = \sum_{t=1}^{T} \frac{Er(t) \cdot Re(t)}{(1+r)^t} \approx CC \cdot carbon \cdot \beta_2 \tag{9}$$

3.3 Carbon Sink of Soil

We can conclude that except for strong human interventions including perceived extensive fertilization and anthropogenic forest destruction, the carbon content of soils in forests fluctuates very little within our forest management plan schedule and can be considered to be essentially constant. To simplify the model, we calculated the carbon content per unit area of land based on forest data in southern China as a reference.

3.4 Forest Fire

It is based on the literature that some carbon from burning trees is converted to carbon dioxide and released directly into the air (Eq 10), while some is converted to charcoal through incomplete combustion and remains in the soil.

$$(C_6H_{10}O_5)_n + 6nO_2 = 6nCO_2 \uparrow + 5nH_2O \tag{10}$$

Thus, after each hill fire, the amount of carbon sequestered in the soil increases by an amount equivalent to a percentage of the carbon content in the burned trees.

4. Case Study: Hongya Forestry

In order to verify our forest system model and solve the problems raised, we chose Hongya Forestry to test our model. The corresponding management plan has a logging intensity of 24.3 % and a rotation period of 46.728 years. We obtain the optimal management plan (BMP) to maximize the overall value of the forest, as shown in the figure 2. The forest management scenario represented by each point of these forest value sets is Pareto optimal, and the four forest value outcomes relating to each scenario are stable.

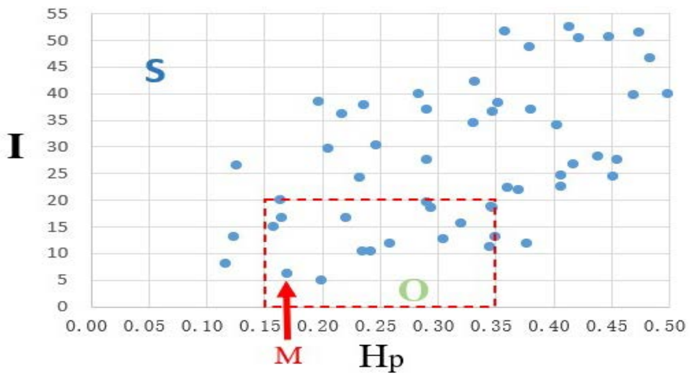
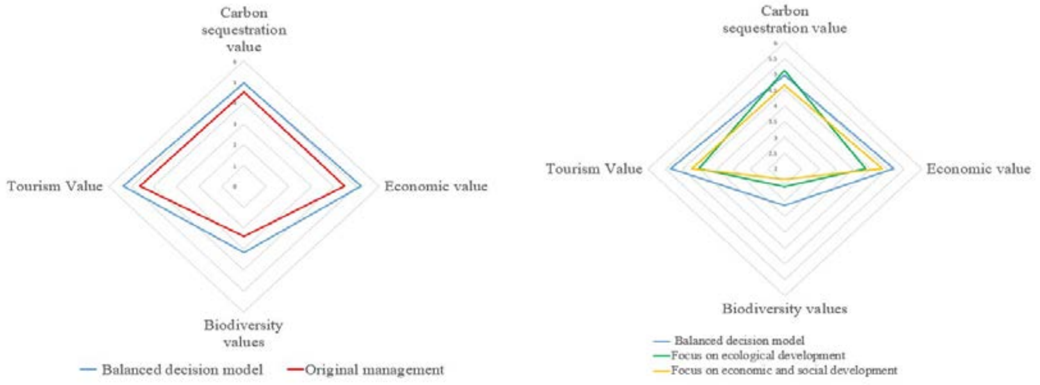


Figure 2: Scatter diagram of pareto optimal solution set

We choose [0.15,0.35]. And the boundary(S) of this graph is the scope of the management plan. The corresponding Pareto solution set is the points in region O. We randomly choose a point M as the quantitative management strategy, and the cutting period of M is 6.30601 and the cutting intensity is 0.16958. To verify that our forest management plan is optimal, we make another two managements. In first management, we assign the economic value to 0.45, tourism value to 0.25, and other weights to 0.1; in second management, we assign 0.45 to the carbon sequestration value of the forest, 0.25 to the biodiversity value, and 0.1 to the others, and the corresponding rotation The following comparison chart is obtained:



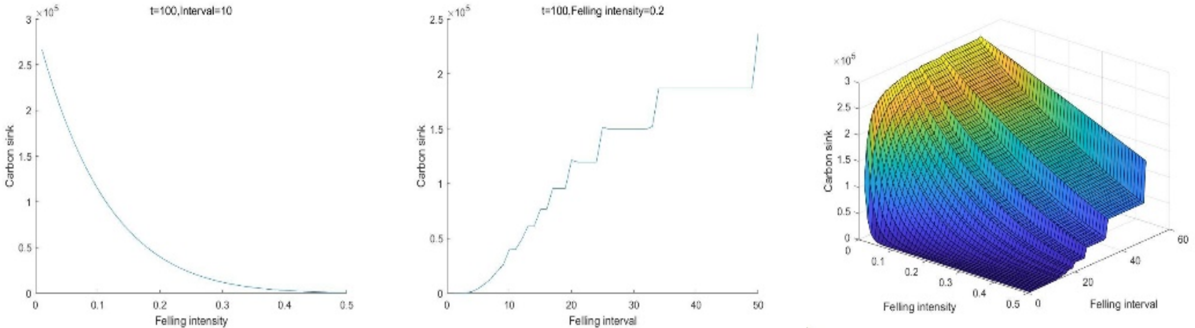
(a) BMP values VS original managed forest values (b) Comparison between management plans

Figure 3: Best Forest Values for BMP

From the information in Figure 3 we can see that our management solutions can maximize the value of all aspects of the forest and achieve the maximum overall forest value.

5. Scalability and Adaptability Analysis

To test the sensitivity of our model, we chose the FBCS model for sensitivity analysis. Making the felling intensity in steps of 0.01 and the felling interval in steps of 1, 50 values each in the feasible forest management range were taken as the test values, and the results are shown in Figure 4, and the sensitivity test shows our model sensitive. This verifies the feasibility of our model and the importance of our proposed forest management plan on felling interval and felling intensity for the growth of forest carbon sinks.



(a) effects of felling intensity on carbon sink (b) effects of felling interval on carbon sink

(c)Combined effects of felling intensity and felling interval on carbon sink

Figure 4: Scalability and adaptability analysis of FBCS model

6. Conclusion

A management plan has a logging intensity of 24.3 % and a rotation period of 46.728 years, which is the most suitable management plan for Hongya forestry and will maximize the overall value of the forest.

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